Non-Lethal Laser System for Sniper Detection via Optical Augmentation[a]

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Abstract

Sniper detection is a challenging and important task for military personnel in hostile combat environments as well as in peace-keeping missions. Laser systems offer a potential advantage over other non-lethal systems by exploiting the retro-reflection, or optical augmentation (OA), inherent from optical systems. The U.S. Air Force Research Lab (AFRL) has recently begun characterizing the return from various optical systems of interest, specifically rifle mounted optical sighting scopes. In parallel with the OA characterization laboratory, we have constructed a prototype OA detection system for validating the laboratory measurement in the field. Results of our OA characterization and field measurements will be presented along with a description of the lab and prototype system. Particular emphasis has been placed on the fact that this is a non-lethal, eye-safe system and application.

I. Introduction

Snipers, sniper rifles and sniper riflescopes are as diverse as the applications for which they are used. A rooftop urban sniper can use a hunting rifle equipped with a good optical sight. The U.S. Marine Corp. M24 sniper weapon system (SWS[1]) uses a 10x42 Leuphold Ultra M3 telescopic sight for daytime sniping and has an effective range of 1000 yards. The Russian Dragonav SVD equipped with a PGN-1 image intensified night scope has a range of 400-500 yards and the heavy long-range barrel Cuban made Mambi[2] sniper rifle is designed for downing helicopters.

To meet the diverse tactical ranges, targets, target motion, and sniper preferences riflescope ma facturers offer a large selection of scope magnifications, reticle features, cross-hair colors and illumination features. However, from a sniper detection standpoint the most critical feature is the design of the sniper scope reticle. Reticles can be grouped into three categories: metal wire type of cross hairs, etched or coated glass substrate reticles and projection reticles. It is the goal of the U.S. AFRL to evaluate a large enough sample of sniper scopes from each of these three categories to develop the ultimate sniper detection system, one that is based on OA technology. Due to the infancy of this program only the metal cross-hair type of reticle has been evaluated both in the laboratory and in field tests. The results of these tests will be presented within the body of this paper along with a description of the AFRL OA laboratory and laser field range. Based on the preliminary results, plans for follow-on activities will also be presented.

II. OA Concept

Optical augmentation (OA) is the term for the use of lasers in detecting retroreflections from optical and electro-optical systems. The common term is the cat's eye effect. The OA detection approach consists of 3 elements: a laser illuminator, an optical target and an

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imaging receiver. The laser is used to illuminate a scene containing a camouflaged sniper who is equiped with sniper rifle and optical sighting scope. In Figure 1 a portion of the laser beam enters the objective lens of the sniper scope and comes to focus in its image plane. The riflescope's image plane is coincident with the placement of the scope's reticle or cross hair. Any and all optical, metallic or coated surfaces have some inherent reflection. A collimated laser beam will focus on the reticle or cross hair and a portion of the laser beam will be retroreflected (like a corner cube) back out of the riflescope in the direction of the transmitter. Due to diffraction effects the return signal will be a far field diffraction pattern with some type of spatial intensity distribution. The angular extent (or spatial distribution) in the plane of the OA detection system's receiver is measured in micro-radians and is called the bistatic angle.

To exemplify the appearance of the radiation pattern in the plane of the OA detection system a composite picture was made by overlaying the scope's 9x boresight OA pattern, as measured in the laboratory with the Battlefield Optical Surveillance System (BOSS[3]) gimbal mounted OA detection system. The result is shown in Figure 2. As can be seen the retroreturn is quite large in angular extent. The specific radiation pattern is dictated by the scope aperture diameter; laser wavelength, type, geometry, texture, and reflectivity of the focal plane surface; the interrogation aspect angle; the focused beam location inside the scope; the proximity of the reticle/cross-hair to the focal plane of the scope; and target range.

The OA return from the covert surveillance system shows up as a bright flash of light on the BOSS video monitor. The bright flash indicates not only the presence of the covert system but also pinpoints its location. If the OA receiver is equipped with a zoom lens, as is the BOSS, the interrogator can zoom in on the flash for target identification. Should the operator confirm the presence of a sniper the target location and grid coordinated is recorded and passed on to the commander for follow up action. Since the BOSS is a non-lethal laser system no active laser countermeasure is used against the sniper.

Still frame images of actual OA signals generated by a metallic wire-type of cross hair and recorded by the BOSS camera during recent night operations are shown in Figures 3 to 6. In Figure 3 a camouflaged sniper, located at a range of 1.2 km, is pointing his rifle far left of the BOSS. At this range with no active laser illumination, the scene is nearly black. With illumination and an image intensified camera details in the terrain can be observed but the sniper can not be identified. However, when the laser is activated and the sniper is boresighted to the BOSS a bright flash of light is clearly visible in the camera's field-of-view (FOV). The results are shown in Figure 4. Even when the sniper looks away and the laser illumination comes to focus at the edge of the sniper's FOV a strong retroreturn is observed. The edge of the FOV condition is shown in Figure 5. For this particular sniper scope OA returns were observed well outside the device FOV. These low-level OA images are shown in Figure 6. The field trials, albeit not all encompassing, demonstrated the utility of OA for sniper detection and location.

III. OA Characterization Laboratory

The AFRL OA laboratory, shown in Figure 7, was developed to perform detailed, parametric and quantitative OA analysis as part of the sniper detection effort. It can also be used to evaluate other optical and electro-optical systems. The quantitative lab data is used to predict (and/or correlate with) the qualitative results obtained during field trials. The lab setup is an un-obscured Fourier Transform Range Simulator (FTRS) geometry. The setup serves as, both, the laser interrogator and as the OA receiver. The major elements are a laser, 2-axis computer controlled scan mirror, off-axis parabola (OAP), imaging receiver, power monitor and a PC based data acquisition & processing station. In the transmitter mode the raw pencil-like laser beam is spatially filtered then expanded to provide uniform illumination over the entire target aperture. The target, like a sniper scope, is mounted in front of the scan mirror and is interrogated in a raster like-pattern. At each interrogation angle the scan mirror illuminates the sniper scope and simultaneously directs the retroreturn back towards the spatial filter. Prior to the spatial filter a beam splitter redirects the retroreturn towards the FTRS sensor where the 2-D OA diffraction pattern is recorded with a CCD camera. The entire image is then digitized and saved for processing. For a typical 128x128 position raster scan 3.7 Gbytes worth of images are acquired and saved. A library of retroreturn images is being established for each device.

In addition to saving the OA images, the station provides a series of 2-D peak differential cross section (PDCS) and average optical cross section (OCS) scan maps for different transmitter/receiver geometries and ranges. The maps can be displayed in intensity, contour and 3-D mesh plot formats. More sophisticated post processing can yield useful information regarding the transmission and the scattering efficiency of the scope optics.

IV. Prototype OA Detection System

The BOSS, shown in Figure 8, consists of a suite of visible, near infrared (NIR) and long wave infrared (LWIR) sensors for passive and active day, low-light level and nighttime battlefield reconnaissance and sniper detection. The sensors and illuminators are distributed between two 2-axis gimbals mounted on a High Mobility Multipurpose Wheeled Vehicle (HMMWV). A comprehensive description of the BOSS is included in an accompanying paper entitled " BOSS: A HMMWV Mounted System for Non-Lethal Point Defense".

The lower gimbal contains a foreward looking infrared (FLIR) sensor while the top gimbal consists of two laser illuminators, which can be turned on independently by the operator, and a combination day/low light level video imaging system. Depending on the ambient light level conditions the operator can select the day only video system or remotely switch to an image intensified camera mode. From an OA perspective the laser illuminator establishes the line of sight to the target (i.e. boresight) and the receiver (i.e. camera) can be considered radially offset from boresite. This type of OA detection is considered to have an offset geometry. The other two types of OA transmitter/receiver geometries are: centrally obscured and un-obscurred. The centrally obscured geometry is where the laser illumination beam is made coincident with the camera's line of sight using a very small turning mirror. This is similar to a Newtonian telescope. The third, unobscured, geometry may be the most optimum design yielding the highest sensitivity for the least amount of laser illumination. Whereas the 1st two geometries are more likely to be considered strap down systems, the 3rd geometry is more of a custom design and hence is more costly to build.

Field trials were conducted with the BOSS illuminating the target scene at 3 ranges (300, 500 and 1200 meters). At the target range the riflescope was mounted either on a 2-axis motor driven pan & tilt head (see Figure 9) or manually aimed by a sniper (see Figure 10). The pan & tilt head was used to precisely position the aimpoint of the riflescope so that the interrogation beam struck different regions of the focal plane. The particular riflescope used contained a metallic wire type of crosshair. Prior to beam irradiation the pan & tilt stage was leveled using a surveyor's level and the riflescope was clocked to assure that the vertical and horizontal crosshairs were coincident with the pan/tilt head's elevation and azimuth drive directions.

During active laser illumination the riflescope was oriented so the beam struck boresight (the intersection of the crosshairs). Then the scope was moved in elevation so the focused laser spot traveled along the crosshair out to and beyond the vertical limit of the scope's FOV. The process was repeated for the azimuth direction. The ability to detect the riflescope when the focused spot was off of the crosshairs was also evaluated. Data was obtained for the upper and lower right quadrants of the scope's FOV. During active illumination the BOSS video signal, showing the OA retroreturn, was video taped. The video was date & time stamped and a test historian recorded a log of events. Radio communication was maintained between the sniper, the BOSS, and historian. Special note was made when the beam was at boresight, ½ way to the edge of the FOV, at the edge of the FOV, outside the riflescope's FOV and in the two quadrants.

In addition to controlled pan & tilt tests the ability to detect an actual sniper, holding the rifle and manually pointing the riflescope in the general direction of the BOSS was evaluated. Video showing the variations of the OA signature as the sniper took aim at the BOSS and at targets within a several hundred meter radius of the BOSS was recorded.

The field trials were conducted under different laser illumination levels in attempt to determine minimum irradiance levels while maintaining OA detection, maximum target detection range, and laser eye safety conditions. During the entire mission the irradiance level at the target site was monitored and recorded with a precision, calibrated, power meter. Though OA detection was achieved with eye-safe irradiance conditions all personnel at the target site wore laser safety glasses with appropriate levels of optical density.

V. Lab & Field OA Results

Laboratory measurements were conducted on the same riflescope that was used for field tests. These measurements were conducted prior to field tests in an effort to predict and plan for the operational tests. High-resolution scan maps were acquired by interrogating the riflescope in 128 (El) x 128 (Az) positions over a 6 (El) x 6 (Az) degree field-of-regard. The resultant PDCS scan maps are shown in Figure 11 for different scope magnification settings and for different receiver geometries. These maps contain a wealth of engineering, scientific and operational data that must be carefully interpreted. The bright regions on the map represent regions within the riflescope that generate high retroreturns. The brightness of the pixels is proportional to the OA signal strength. Figures 11a and 11b represent the resultant scan maps for the case where the search region for peak cross section extends the entire FTRS receiver FOV. Figure 11a and 11b represent the scan map for the 3x and 9x scope magnification, respectively. These maps show that raster scanning the scope creates an OA map of the riflescope's focal plane and that the regions of high retroreturn correspond to the scope's metallic crosshair. The maps also show that the angular detection range is governed by the scope magnification. Since lower magnification implies wider scope FOV, the sniper can be detected over a wider interrogation angle. When the sniper is zooming in on his target, the detection angle is reduced proportionally.

To evaluate the effect of transmitter/receiver geometry saved images, acquired during the 9x magnification condition, were processed for a monostatic receiver (modeled as a 3 x 3 pixel search region about the FTRS boresight) and for the BOSS offset geometry. The PDCS maps corresponding to these two geometries are shown in Figures 11c and 11d. The maps look similar to the map generated by the entire FTRS FOV search region (Figure 11b) but the detail is not quite the same and the amplitudes of the PDCS are different. The differences between the maps are be governed by the riflescope diffraction pattern and intensity as a function of bistatic angle.

This is more clearly seen in Figure 12 where the mean OCS maps are shown for different target ranges. Figure 12 consists of six FTRS outputs grouped into 2 sets. Each set represents data for a given range; 300, 500, and 1200 meters. The left most output in each set is the FTRS image of the bistatic diffraction pattern obtained from the riflescope's boresight position. Superimposed on it is a white square indicating the apparent angular size and location of the BOSS's off-axis receiver geometry. The area inside the white box represent the portion of the retroreturn that is intercepted by the BOSS receiver at that range. The right figure in each set represents the mean OCS scan map for that range and apparent receiver size. The mean scan map is presented as a meshplot (top of the right figure) and as a 2-D intensity image (bottom of right figure). The results of Figure 12 show that the geometry of the OA detection system and the shape of the diffraction pattern govern the mean OCS of the riflescope.

The data for the 300 m range is shown in Figures 12a - 12b. At this close range the receiver appears to have a large angular extent but because of the offset it intercepts only the edge of the scope's diffraction pattern. The mean OCS scan map for the BOSS. at the 300 m range, is shown in Figure 12b.

At 500 meters the angular extent of the receiver reduces in size and the offset becomes smaller, as can be seen in Figure 12c. This search region contains pixels with higher signal strength which results in a brighter mean OCS scan map (Figure 12d).

As the target range increases the search region approaches, and at infinity converges, to OA detection system's boresight position. The long range, 1.2 km data is shown in Figures 12e and 12f. The OA signature from the crosshairs is starting to fill in the map is beginning to look more like the monostatic PDCS map in Figure 11d.

I. Future Plans

Based on the successful laboratory and field tests the laboratory effort will be expanded to speed up data acquisition and post processing. In addition a reconfigurable breadboard OA field table will be developed to evaluate different geometries & wavelengths. AFRL is actively seeking collaboration, under a Cooperative Research and Development Agreement (CRADA), with scope manufactures to perform OA characterization and field tests various riflescopes.

VII. Summary/Conclusion

The laboratory and field tests clearly indicate that the application of OA to detecting snipers is a viable technology and that further research and development into this approach is warranted. However, any field tests must be coordinated with OA laboratory analysis. The data clearly indicates that, prior to performing field OA detection tests, the OA signature of the target should be characterized in a benign laboratory environment for the particular OA detection's transmitter/receiver geometry and target range.

The OA laboratory measurements also provide useful engineering data regarding the source of OA retroreturns and the scattering efficiency of the riflescope's optics. This area of investigation should also be exploited. The field test results tracked the laboratory scan map data. However, a few positive anomalies were observed which warrant further investigation.

Acknowledgements

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References

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2 *Albuquerque Journal, from the Associated Press, 3 December 1996*

3 *W.T. Cooley, Capt., USAF, T.P. Davis, Lt., USAF, J.M. Kelly, "BOSS: A HMMWV Mounted System for Non-Lethal Point Defense", ADPA/NSIA Non-Lethal Defense III Conference, 25-26 Feb 1998.*

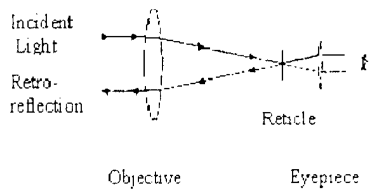


Figure 1: OA Concept

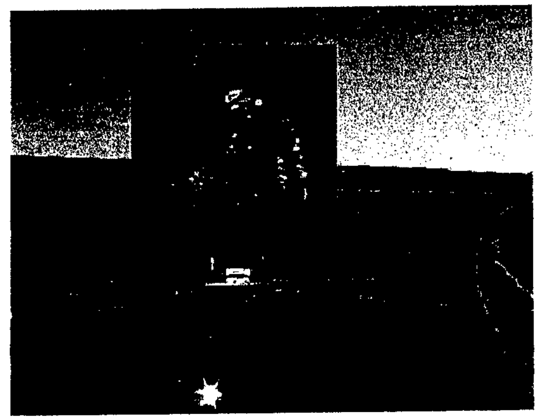


Figure 2: OA Diffraction Pattern

Figure 3: Sniper Looking Far Left

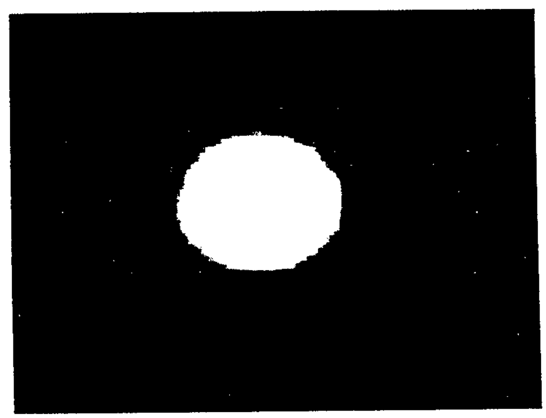


Figure 4: OA from Sniper's Boresight

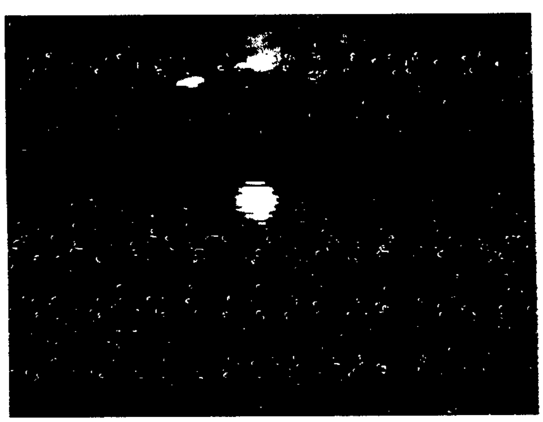


Figure 5: OA from Sniper's Edge of FOV

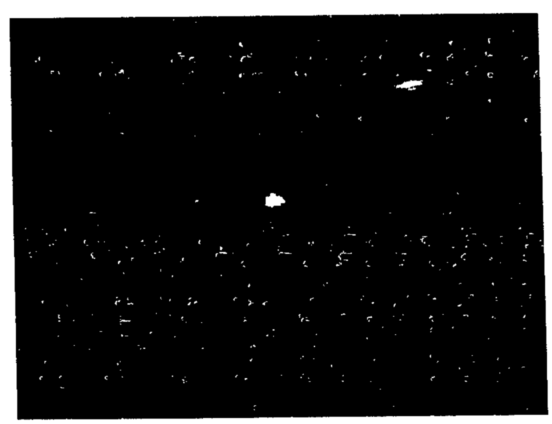


Figure 6: OA from Outside Sniper's FOV

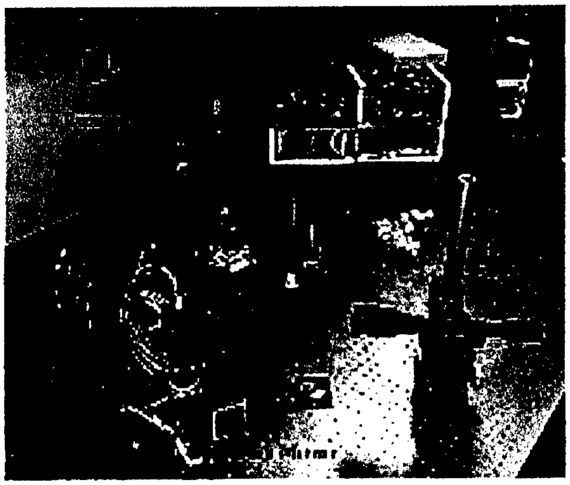


Figure 7: OA Lab Setup

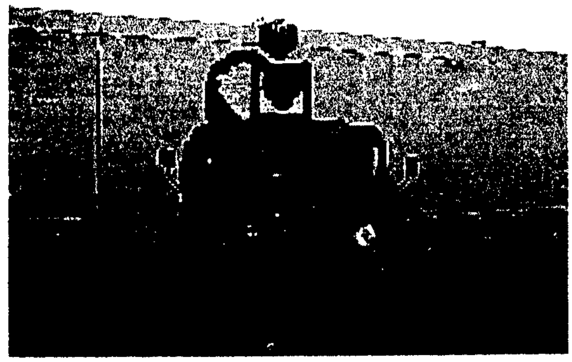


Figure 8: BOSS

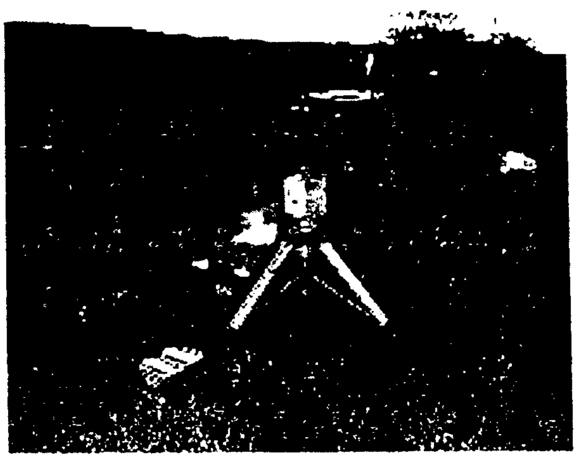


Figure 9: Rifle and Scope Field Setup

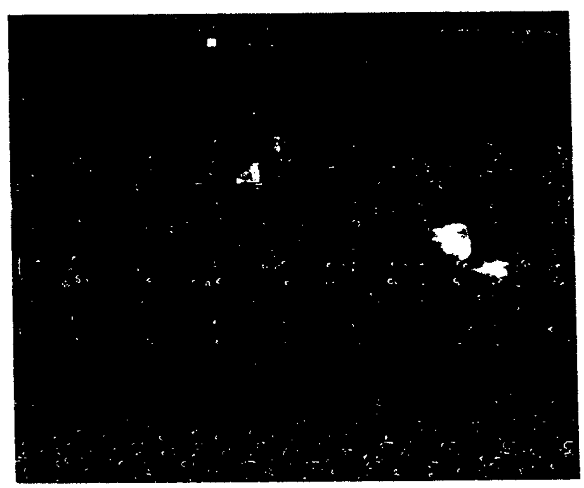


Figure 10: Sniper with Rifle and Scope

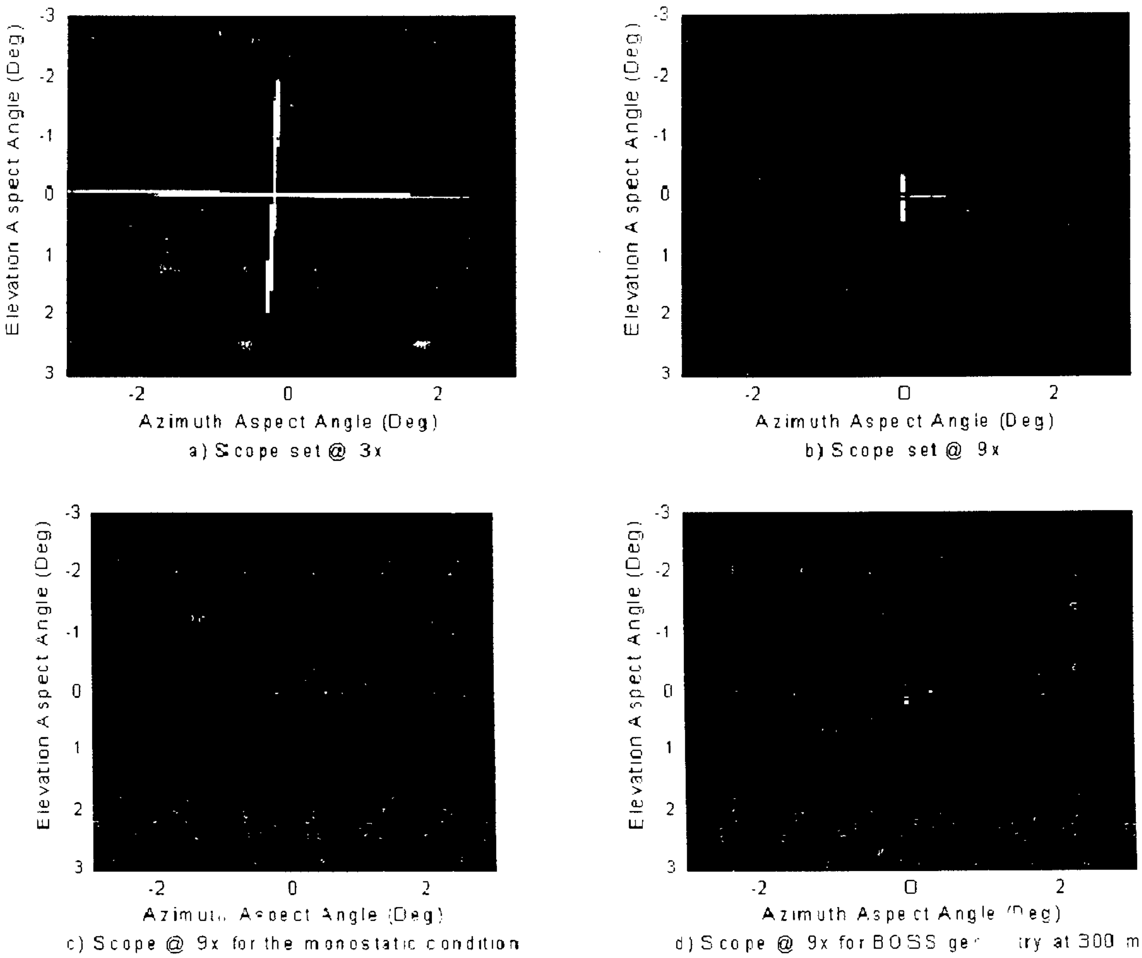
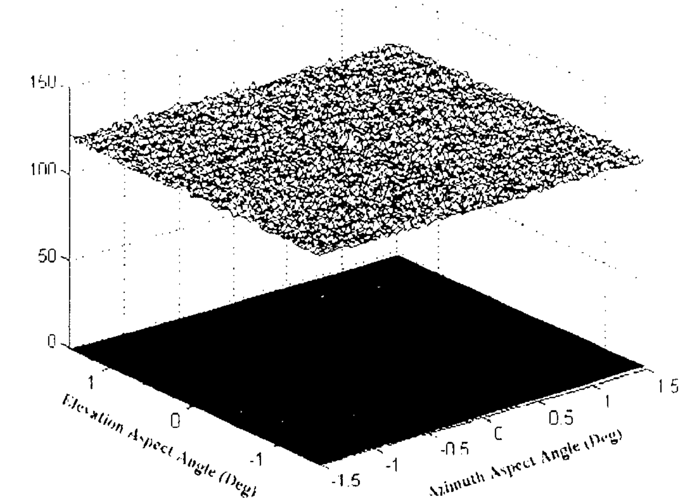


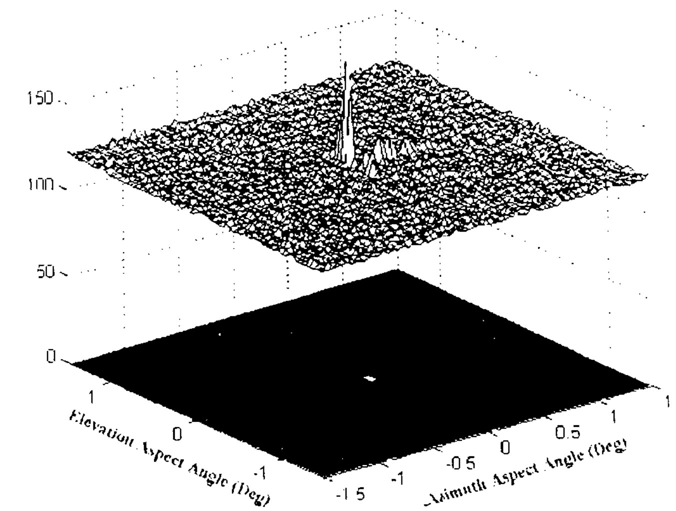
Figure 11: Various PDCS maps for same rifle scope

a) **BOSS Bistatic Search Region**

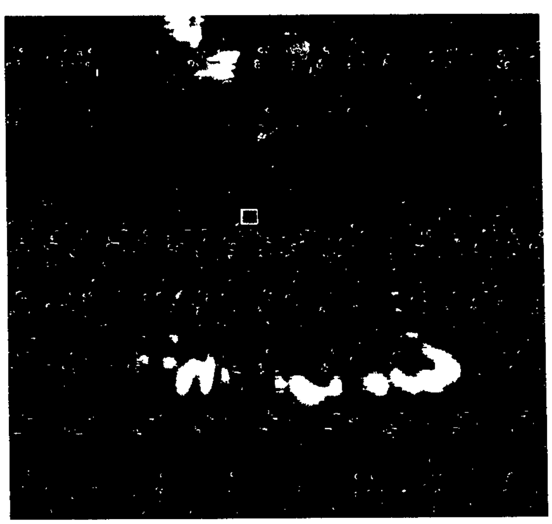


b) **Mean OCS Map @ 300 m**

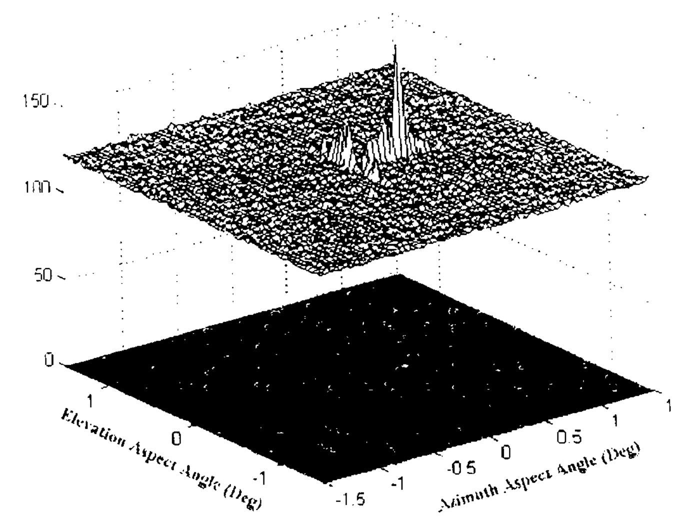
c) **BOSS Bistatic Search Region**



d) **Mean OCS Map @ 500m**



e) **BOSS Bistatic Search Region**



f) **Mean OCS Map @ 1.2 km**

Figure 12: Average OCS maps for BOSS geometry @ various ranges